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CHAPTER 27
LIFE-CYCLE COSTING[1]

GENERAL DISCUSSION

Contractors and design professionals need practical methods and guidelines for evaluating the economic performance of mechanical systems in buildings. Life-cycle cost (LCC) analysis is one method for making such evaluations. LCC analysis is used to evaluate alternative systems which compete on the basis of cost. Thus only candidate systems which satisfy all performance requirements (e.g., code, safety, comfort, and reliability requirements) can be legitimately compared using the LCC method. The system alternative with the lowest LCC over the project study period is the most cost-effective choice.

An example of an appropriate use of the LCC method is choosing between an oil furnace and gas furnace for heating a building. To be candidate projects for an LCC analysis, each system must meet the minimum performance requirements for occupant comfort, and the fuel required for each system must be available at the site. The cost-effective choice will depend on which system has lower LCCs over the project study period, assuming other things equal.

Systems with the lowest LCC often have higher first costs than competing systems. This leads builders to ask why they should put out more money up front than is necessary, particularly when they plan to sell the building on completion. One answer is that the builder might expect a return on the cost-effective system that more than compensates for its extra costs. This happens, for example, if the owner-operator achieves sufficient net savings over time from reduced energy consumption to more than pay the builder's extra first costs and profit required for installing the cost-effective system.

This chapter describes how to measure LCCs and use the LCC method in choosing among alternative building systems. A sample problem using the LCC method shows how to find the cost-effective efficiency level of an air-conditioning system. And a sample problem using the savings-to-investment ratio (SIR), an evaluation method related to LCC, shows how to find the optimal combination of independent energy-conservation investments when there is too little money to do all the projects which return positive net savings.

The chapter also provides a brief overview of other measures of project worth, such as net savings and payback, and identifies circumstances when they might be appropriate. It has a section on how to treat uncertainty with sensitivity analysis. A list of definitions of economics terms is provided at the end of the chapter for your help whenever you see a term that is unfamiliar. Selected references conclude the chapter.

[1]By Harold E. Marshall and Stephen R. Petersen, National Institute of Standards and Technology, Gaithersburg, Md.

HOW TO MEASURE AND APPLY LCC

Equation (27.1) shows that the LCC of a project alternative is the sum of its initial investment costs I, present value of replacement costs R, present value of energy costs E, and the present value of operation, maintenance, and repair (OM&R) costs, minus the present value of salvage S, which is sometimes referred to as *resale value* or *residual value.*

$$LCC = I + R + E + OM\&R - S \tag{27.1}$$

Equation (27.2) is an alternative formulation that shows mathematically the discounting of future costs to present value and their summation into a single LCC calculation.

$$LCC = \sum_{t=0}^{N} \frac{C_t}{(1 + d)^t} \tag{27.2}$$

where C_t = sum of all relevant costs, less any positive cash flows such as salvage, occurring in time period t

N = number of time periods in the study period

d = investor's discount rate for adjusting cash flows to present value

Steps in LCC Analysis

The following list shows the steps to follow in conducting an LCC analysis:

1. Identify acceptable alternatives.
2. Establish common assumptions (e.g., study period, discount rate, and base date).
3. Estimate all project costs and their timing.
4. Discount future costs to present value.
5. Compute total LCC for each alternative.
6. Identify alternative with lowest LCC.
7. Consider unquantifiable costs and benefits.
8. Consider uncertainty in input values.
9. Compute supplementary measures of relative economic performance (if necessary).
10. Select best alternative.

Rules in Applying the LCC Method

To use the LCC method, you need to compute the LCC of a project alternative (sometimes called the *base case*) against which to compare the LCCs of your proposed design alternative(s). Usually the base case is the alternative with the lowest initial cost.

For each alternative you consider, you must use the same discount rate and the same study period (i.e., time over which you compare the alternatives). Only then can you determine which is more cost-effective. To come up with a common study period, you will sometimes have to include replacements in short-lived projects and account for salvage value in long-lived projects.

An implicit assumption in LCC analysis is that all the alternatives that you are considering for a particular project be capable of satisfying the minimum performance requirements for that project (e.g., safety, reliability, occupant comfort, and other building code requirements). Consider the extent to which any alternative exceeds such minimum performance requirements as additional benefits attributable to that alternative. If the additional benefits can be quantified in dollar terms (e.g., additional rental income), treat these benefits as negative costs in the years in which the benefits are realized. If the additional benefits cannot be quantified in dollar terms, include a description of these benefits in narrative form with the LCC analysis. Then use your own (or institutional) judgment to determine the extent to which the LCC penalty (if any) for a particular alternative is offset by such benefits. For example, air conditioner B costs $1,000 more initially than air conditioner A, but saves only $900 in present-value energy costs over air conditioner A. Air conditioner B, on the other hand, is significantly quieter than A. Thus air conditioner B could be the "economic" choice from the owner's standpoint, even though its LCC is $100 higher, if the owner considers this acoustic benefit as being worth at least the extra $100 in present-value LCC terms.

If project alternatives have substantial differences in performance that result in large positive cash flows, the LCC method may not be the most appropriate method of economic analysis. Instead, use net benefits or related methods of economic analysis that account explicitly for benefits as well as costs over the appropriate study period.

LCC Applied to the Choice of an Air-Conditioning System

Suppose you are selecting a new central air conditioner for installation in a house with a design cooling load of 38.0 MJ/hr (i.e., 36,019 Btu/hr) in a region with approximately 1,500 full-load cooling hours per year. The system with the lowest initial cost that meets the Department of Energy's current energy performance standards has a *seasonal energy-efficiency ratio* (SEER) of approximately 10.55 kJ/Wh (10.0 Btu/Wh). Because the cooling load hours are above average, you will probably also want to consider systems with SEERs of 12.66 and 14.77 kJ/Wh (12.0 and 14.0 Btu/Wh), even though their initial costs are higher. The LCC method helps you determine which SEER will result in the lowest LCC over a 15-year study period.

Local electricity rates are currently $0.08/kWh (summer rates), with no demand charge, and are expected to increase at about 3% per year. Let's use an 8% discount rate to convert future costs (including price increases) to present value. All three systems have an expected life of 15 years and approximately the same maintenance costs.

Table 27.1[2] shows the computation of LCC for each alternative system, based on the sum of the initial cost and present value energy costs for each system. The BLCC computer program described at the end of this chapter will help you do the LCC Analysis. System B has the lowest LCC (Column 7, Table 27.1) and is therefore the economic choice, assuming that its reliability, maintenance, and sound characteristics are not worse than those of system A or C.

Note that if the local utility were to offer a cash rebate for selecting a higher efficiency air conditioner, the initial investment cost (Column 6, Table 27.1) should be reduced accordingly for systems B and C. Based on the rebates reflected in Column 8 (Table 27.1), system C becomes the most economic choice.

Typical LCC Applications

Accept/reject decisions occur when you have to decide whether to do a project. Examples are the installation of solar water heating, storm windows, or a water-heater insulation kit. These can be evaluated as independent projects as long as an investment in one does not affect the savings of another. This would be true, for example, if they were in different buildings. The

[2]The tables in this chapter do not appear on the computer disk provided with this book.

TABLE 27.1 Computation of LCC for Three Air Conditioners

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					Without utility rebate		With utility rebate	
System	SEER Btuh/W	Annual kWh use	Annual kWh cost, $	PV kWh cost, $	Initial AC cost, $	Total LCC, $	Initial AC cost, $	Total LCC, $
(A)	10.0	5,400	432	4,527	2,000	6,527	2,000	6,527
(B)	12.0	4,500	360	3,773	2,500	6,273	2,200	5,973
(C)	14.0	3,855	308	3,234	3,100	6,334	2,500	5,734

Explanation and computation of values (numbers in parentheses refer to column numbers):

(2) from product literature

(3) = 36,000 Btuh/SEER (Btuh/W) × 1,500 h/year

(4) = (3) × $0.08/kWh

(5) = (4) × 10.48, where 10.48 is the UPV* factor for an annually recurring cost increasing at a rate of 3% and discounted at 8% per year, based on the equation

$$\text{UPV}^* = \frac{(1+e)}{(d-e)}\left(1 - \frac{(1+e)^n}{(1+d)^n}\right) \text{ (when } e \neq d\text{, else UPV}^* = n)$$

where e = the annual rate of price increase
d = discount rate, and
n = number of time periods

(6) estimated installed cost

(7) = (5) + (6)

(8) assumed rebate for SEER 12 = $300; assumed rebate for SEER 14 = $600

(9) = (5) + (8)

LCC can help you decide if it pays to undertake any one of these projects compared to its base case. Accept the storm windows, for example, if their LCC is less than the LCC of the base case.

Efficiency level or size decisions occur when you must decide how much of something to invest in. Examples are choosing the seasonal efficiency rating of an air conditioner, the collector area for a solar energy system, or the level of thermal resistance for wall insulation. Make these types of decisions by choosing the level or size with the minimum LCC.

System or design decisions occur when you choose the most cost-effective of multiple alternatives for meeting an objective. For example, the LCC method can help you choose among oil, gas, or electricity for heating; among fiber-glass, foam, or cellulose for insulation material; and between a heat pump or electric resistance baseboard system. Choose the alternative with the minimum LCC as long as it satisfies system performance requirements.

OTHER METHODS AND WHEN TO USE THEM

Net Savings (NS) or Net Benefits (NB)

The NS method measures the amount of present value net savings earned over the study period from investing in a candidate project as compared to a base-case alternative. When an investment affects costs exclusively, a common approach to computing NS is to compare the LCC associated with the investment to the LCC of the base-case alternative. The NS for a heat pump, for example, is the difference between the LCC of heating and cooling a house to a target comfort level with the base-case system, say, an oil furnace with electric air conditioner, and the LCC of heating and cooling with the heat pump. If NS with the heat pump is positive, the investment makes money and is considered cost-effective; if NS is zero, the investment neither makes nor loses you money; if NS is negative, the investment loses money.

Use the NB method when positive revenues or benefits rather than savings accrue from the project. Either NS or NB is appropriate for accept/reject, size, or design decisions. For detailed information on how to calculate, apply, and interpret the NS and NB methods, see Ruegg and Marshall.[5]

Savings-to-Investment Ratio (SIR)

Equation (27.3) shows that the SIR of a project alternative is the sum of its present-value (PV) savings divided by the sum of the present value of all investment-related costs attributable to that alternative over the base case.

$$\mathrm{SIR}_{A:BC} = \frac{\sum_{t=1}^{N} S_t \Big/ (1+d)^t}{\sum_{t=0}^{N} I_t^* \Big/ (1+d)^t} \tag{27.3}$$

where $\mathrm{SIR}_{A:BC}$ = the ratio of PV savings to additional PV investment costs of the alternative (A) relative to the base case (BC)

S_t = PV savings in year t in operating-related costs attributed to the alternative

I_t^* = additional PV investment-related costs attributable to the alternative in year t

Steps in SIR Analysis. The steps in performing an SIR analysis are similar to those shown under LCC analysis (above), except that for the SIR you need to calculate specific savings from each alternative rather than just its LCC.

Rules in Applying the SIR Method. The main rule to remember in using the SIR is to place in the denominator of the SIR formula any investment-related cost on which you are seeking to measure your investment return. The placement of items in the numerator and denominator can alter the relative priority of a project within a group of cost-effective projects, but will not cause a project alternative with an SIR > 1.0 to fall below 1.0 or vice versa.

Typical Applications of SIR. One use of the SIR is to make accept/reject decisions for single projects. Accept the project if the SIR > 1.0; reject it if the SIR < 1.0.

A second use of the SIR is to choose among cost-effective projects when the investment budget is limited. When money is not available to fund every building or system improvement that is cost-effective, try to allocate funds so that the overall net savings (total savings less total investment cost) are maximized from the project selection. An appropriate method for allocating limited funds among independent projects is to rank projects in declining order of their SIRs, and then fund them in that order until the budget is exhausted. The package of investment options selected by SIR ranking will generate the greatest net savings overall relative to any other package. This works for allocating a budget within a single building or

[5] Rosalie T. Ruegg and Harold E. Marshall, *Building Economics: Theory and Practice*, Chapman and Hall, New York, August 1990, pp. 34–47.

among many buildings to which a single budget applies. The projects must be functionally independent, however, for the SIR allocation method to work. That is, the savings from one project cannot significantly affect the savings from another.

The SIR ranking applies only to additional investments required by building system options which are expected to reduce future costs relative to the basic system. It is assumed that, at a minimum, the basic system must be installed for the building to function properly. For example, an SIR would not be calculated for the lowest first-cost (and presumably least efficient) air-conditioning system that meets the cooling requirements of a new building. But it would be calculated for the additional investment required to install a higher efficiency air conditioner. Furthermore, this SIR would only be compared to SIRs for other independent improvements (e.g., heating system improvements) to determine how to allocate a fixed budget among such improvements.

SIR Applied to Choosing among Independent Projects When the Budget Is Limited. Table 27.2 shows how to use the SIR in choosing among five building improvements for energy reduction in a new building. Each improvement is cost-effective because the SIR of each exceeds 1.0. But total investment costs for the improvements are $10,000, and only $5,000 is available to invest. In this case, the SIR ranking indicates that improvements A, B, and D should be selected. (Improvement C, while having an SIR higher than that of D, will break the budget, so you skip over it and choose D.) If $7,000 of funding were available, select improvements A, B, and C.

TABLE 27.2 SIR Ranking of Building Improvements

	Initial cost, $	PV savings, $	SIR
A. Improved lighting fixtures	2,500	10,000	5.0
B. Improved roof deck insulation	2,000	7,000	3.5
C. Higher-efficiency window systems	2,500	7,500	3.0
D. Higher-efficiency water heater	500	1,250	2.5
E. Automatic entry doors (to reduce uncontrolled air leakage)	2,500	5,000	2.0

Payback

Payback (PB) measures how long it takes to recover investment costs. If you ignore the time value of money when you compute the payback period (i.e., you use a zero discount rate), you have simple payback (SP). If you account for the time value of money by using a positive discount rate, you have discounted payback (DPB). The DPB is a more accurate measure of payback because the time value of money is taken into account.

Investors sometimes specify a maximum acceptable payback period (MAPP) for evaluating a building system. For example, a high-efficiency heat pump might be chosen over a conventional heat pump only if the higher first cost is returned through fuel savings in, say, 2 years (the MAPP). But we discourage using some arbitrary MAPP to select systems because it is an unreliable guide to cost-effective choices.

PB is easy to understand, however, and as a supplementary method, it may be helpful in screening potential projects quickly. It is also useful to determine how long it takes for a project to break even. But it is a poor measure of a project's profitability over the long run because it ignores cash flows after payback. And if you use SP, it will not even give you a reliable measure of the time to break even. So try to use LCC, NS, and SIR methods instead of PB when making economic decisions.[4]

Uncertainty and Sensitivity Analysis

Long-lived investments such as building mechanical systems are characterized by uncertainties regarding project life, operation and maintenance costs, and other factors that affect project economics. Since values of these variable factors are generally unknown, it is difficult to make economic evaluations with a high degree of certainty. One approach to this uncertainty problem is to use sensitivity analysis. It is a simple, inexpensive technique for handling uncertainty that gives you some perspective of how far off your measures of project worth might be.

Sensitivity analysis measures the impact on project outcomes of changing one or more key input values about which there is uncertainty. For example, a pessimistic value, expected value, and optimistic value might be chosen for an uncertain variable. Then an analysis could be performed to see how the outcome changes as you consider each of the three chosen values in turn, with other things held the same. When computing measures of project worth, for example, sensitivity analysis shows you just how sensitive the economic payoff is to uncertain values of a critical input, such as the discount rate, project maintenance costs, and mechanical equipment service life. Table 27.3 provides ASHRAE service life data for many types of mechanical equipment.[5] Analysis reveals how profitable or unprofitable the project might be if input values to the analysis turn out to be different from what is assumed in a single-answer approach to measuring project worth.

Sensitivity analysis can also be performed on different combinations of input values. That is, several variables are altered at once and then a measure of worth is computed. For example, one scenario might include a combination of all pessimistic values; another, all expected values; and a third, all optimistic values. Note, however, that sensitivity analysis can in fact be misleading if all pessimistic assumptions or all optimistic assumptions are combined in calculating economic measures.[6] Such combinations of inputs would be unlikely in the real world.

Sensitivity analysis can be performed for any measure of worth. And since it is easy to use and understand, it is widely used in the economic evaluation of government and private-sector projects. Office of Management and Budget Circular A-94[7] recommends sensitivity analysis to federal agencies as one technique for treating uncertainty in input variables. And the American Society for Testing and Materials (ASTM), in its "Standard Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems,"[8] describes sensitivity analysis for use in government and private-sector applications.

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[4] For more details on when to apply these methods, see the video and workbook *Choosing Economic Evaluation Methods*, Part III in a series entitled Least-Cost Energy Decisions for Buildings, National Institute of Standards and Technology, 1993.

[5] An analyst using equipment service lines, for example, as shown in Table 27.3, might want to calculate measures of worth for higher and lower values of project life in addition to the measure of worth based on the median life shown in the table.

[6] F. Hillier, "The Derivation of Probabilistic Information for the Evaluation of Risky Investments," *Management Science*, p. 444.

[7] Office of Management and Budget, revised Oct. 29, 1992. Circular A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," pp. 12–13.

[8] American Society for Testing and Materials, "Standard Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems," E1369-93, *ASTM Standards on Building Economics*, 3d ed., Philadelphia, Pa., 1994.

TABLE 27.3 Mechanical Equipment Service Life

Service life is a time value established by ASHRAE that reflects the expected life of a specific component. Service life should not be confused with useful life or depreciation period used for income tax purposes. It is the life expectancy of system components. Equipment life is highly variable because of the diverse equipment applications, the preventive maintenance given, the environment, technical advancements of new equipment, and personal opinions. The values in this table are a median listing of replacement time of the components. Service life can be used to establish an amortization period or, if an amortization period is given, service life can give insight into adjusting the maintenance or replacement costs of components.

Equipment item	Median years	Equipment item	Median years
Air conditioners		Coils	
Window unit	10	DX, water, or steam	20
Residential single or split package	15	Electric	15
Commercial through-the-wall	15	Heat exchangers	
Water-cooled package	15	Shell-and-tube	24
Computer room	15	Reciprocating compressors	20
Heat pumps		Package chillers	
Residential air-to-air	—*	Reciprocating	20
Commercial air-to-air	15	Centrifugal	23
Commercial water-to-air	19	Absorption	23
Rooftop air conditioners		Cooling towers	
Single-zone	15	Galvanized metal	20
Multizone	15	Wood	20
Boilers, hot water (steam)		Ceramic	34
Steel water-tube	24 (30)	Air-cooled condensers	20
Steel fire-tube	25 (25)	Evaporative condensers	20
Cast iron	35 (30)	Insulation	
Electric	15	Molded	20
Burners	21	Blanket	24
Furnaces		Pumps	
Gas- or oil-fired	18	Base-mounted	20
Unit heaters		Pipe-mounted	10
Gas or electric	13	Sump and well	10
Hot water or steam	20	Condensate	15
Radiant heaters		Reciprocating engines	20
Electric	10	Steam turbines	30
Hot water or steam	25	Electric motors	18
Air terminals		Motor starters	17
Diffusers, grilles, and registers	27	Electric transformers	30
Induction and fan-coil units	20	Controls	
VAV and double-duct boxes	20	Pneumatic	20
Air washers	17	Electric	16
Ductwork	30	Electronic	15
Dampers	20	Valve actuators	
Fans		Hydraulic	15
Centrifugal	25	Pneumatic	20
Axial	20	Self-contained	10
Propeller	15		
Ventilating roof-mounted	20		

*Data removed by TC 1.8 because of changing technology.

SOURCE: Obtained from a nationwide survey conducted in 1977 by ASHRAE TC 1.8 (RP 186).

Sensitivity Analysis Application. The results of sensitivity analysis can be presented in text, tables, or graphs. The following illustration of sensitivity analysis applied to a programmable control system uses text and a simple table.

Consider a decision on whether to install a programmable time clock to control heating, ventilating, and air conditioning (HVAC) equipment in a commercial building. The time clock would reduce electricity consumption by turning off HVAC equipment that is not needed during hours when the building is unoccupied.

Using net savings (NS) as the measure of project worth, the time clock is acceptable on economic grounds if its NS is positive, that is, if its present-value savings exceed present-value costs. The control system purchase and maintenance costs are felt to be relatively certain. The savings from energy reductions resulting from the time clock, however, are not certain. They are a function of three factors: the initial price of energy, the rate of change in energy prices over the life cycle of the time clock, and the number of kilowatt hours (kWh) saved. Two of these, the initial price of energy and the number of kWh saved, are relatively certain. But future energy prices are not.

To test the sensitivity of NS to possible energy price changes, three values of energy price change are considered: a low rate of energy price escalation (slowly increasing benefits from energy savings), a moderate rate of escalation (moderately increasing benefits), and a high rate of escalation (rapidly increasing benefits).

Table 27.4 shows three NS estimates that result from repeating the NS computation for each of the three energy price escalation rates.

TABLE 27.4 Energy Price Escalation Rates

Energy price escalation rate	Net savings, $
Low	−15,000
Moderate	20,000
High	50,000

To appreciate the significance of these findings, it is helpful to consider what extra information you now have over the conventional single-answer approach where, say, you computed a single NS estimate of $20,000. Table 27.4 shows that the project could return up to $50,000 in NS if future energy prices escalated at a high rate. On the other hand, you see that the project could lose as much as $15,000. This is considerably less than breakeven, where the project would at least pay for itself. It is also $35,000 less than what you calculated with the single-answer approach. Thus sensitivity analysis alerts you that accepting the time clock could lead to an uneconomic outcome.

There is no explicit measure of the likelihood that any one of the NS outcomes will happen. The analysis simply tells you what the outcomes will be under alternative conditions. However, if there is reason to expect energy prices to rise, at least at a moderate rate, then the project very likely will make money, other factors remaining the same.

This adds helpful information over the traditional, single-answer approach to measures of project worth.

Advantages and Disadvantages of Sensitivity Analysis. There are several advantages of using sensitivity analysis in engineering economics. First, it shows how significant any given input variable is in determining a project's economic worth. It does this by displaying the range of possible project outcomes for a range of input values. This shows decision makers the input values that would make the project a loser or winner. Sensitivity analysis also helps you identify critical inputs so that you can choose where to spend extra resources in data collection and in improving data estimates. Second, sensitivity analysis is an excellent technique to help you anticipate and prepare for the "what-if" questions that you will be asked when presenting and defending a project. When you are asked what the outcome will be if operating costs are 50% more expensive than you think, you will be ready with an answer. Generating answers to what-if questions will help you assess how well your proposal will stand up to scrutiny. Third, sensitivity analysis does not require the use of probabilities as do many techniques for treating uncertainty. Fourth, you can use sensitivity analysis on any measure of project worth. And finally, you can use it when there is insufficient information, resources, and time for more sophisticated techniques.

The major disadvantage of sensitivity analysis is that there is no explicit probabilistic measure of risk exposure. That is, while you might be sure that one of several outcomes might happen, the analysis contains no explicit measure of their respective likelihoods.

For techniques that go beyond sensitivity analysis and give you some measure of your risk of choosing an uneconomic project, see the video and workbook *Uncertainty and Risk*, Part II in a series entitled Least-Cost Energy Decisions for Buildings.[8]

DEFINITIONS OF ECONOMIC TERMS

Base case: The base-case alternative is the alternative against which proposed alternatives are compared.

Base date: The date (usually the beginning of the study period) to which benefits and costs are converted to time equivalent values when using the present-value method.

Breakeven: A combination of benefits (savings or revenues) that just offset costs, such that a project generates neither profits nor losses.

Cost effective: The condition whereby the present-value benefits (savings) of an investment alternative exceed its present-value costs.

Discount rate: The minimum acceptable rate of return used in converting benefits and costs occurring at different times to their equivalent values at a common time. Discount rates reflect the investor's time value of money (or opportunity cost). *Real* discount rates reflect time value apart from changes in the purchasing power of the dollar (i.e., exclude inflation or deflation) and are used to discount constant dollar cash flows. *Nominal* or *market* discount rates include changes in the purchasing power of the dollar (i.e., include inflation or deflation) and are used to discount current dollar cash flows.

Discounting: A procedure for converting cash amounts that occur at different points in time to an equivalent amount at a common point in time.

Life-cycle cost (LCC): The sum of all discounted costs of acquiring, owning, operating, maintaining, and disposing of a building project over the study period. Comparing life-cycle costs among mutually exclusive projects of equal performance is one way of determining relative cost effectiveness.

Measures of project worth: Economic methods which combine project benefits (savings) and costs in various ways to evaluate the economic value of a project. Examples are life-cycle costs, net benefits or net savings, benefit-to-cost ratio or savings-to-investment ratio, and payback.

Net savings: The difference between savings and costs, where both are discounted to present or annual values. The net savings method can be used as a measure of project worth.

[8] *Uncertainty and Risk*, Part II in a series entitled Least-Cost Energy Decisions for Buildings, National Institute of Standards and Technology, 1992.

Present value: The time-equivalent value at a specified base time (the present) of past, present, and future cash flows.

Risk exposure: The probability that a project's economic outcome is different from what is desired (the target) or what is acceptable.

Salvage value: The residual or resale value, net of any disposal costs, of any system removed during the study period or remaining at the end of the study period.

Savings-to-investment ratio (SIR): The ratio of present-value savings to present-value investment costs. The SIR method is used to make accept/reject decisions for single projects and to choose among independent projects when the investment budget is limited.

Sensitivity analysis: A technique for measuring the impact on project outcomes of changing one or more key input values about which there is uncertainty.

Study period: The length of time over which an investment is evaluated, generally set equal to the life of the project or the time horizon of the investor, whichever is shorter.

Uncertainty: Uncertainty (or certainty) as used in this chapter refers to a state of knowledge about the variable inputs to an economic analysis. If the analyst is unsure of input values, there is uncertainty. If the analyst is sure, there is certainty.

RECOMMENDED READING

American Society for Testing and Materials, "Standard Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems," E1369-93, *ASTM Standards on Buildings Economics,* 3d ed., Philadelphia, Pa., 1994.

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Petersen, S. R., *BLCC 4.0—The NIST "Building Life-Cycle Cost" Program User's Guide and Reference Manual,* NISTIR 5185, National Institute of Standards and Technology, Gaithersburg, Md., 1993.

Ruegg, R. T., and H. E. Marshall, *Building Economics: Theory and Practice,* Chapman and Hall, New York, August 1990.

RECOMMENDED SOFTWARE

Building Life-Cycle Cost (BLCC)

BLCC is a public-domain computer program developed at NIST for the economic analysis of buildings and building systems. It is designed to run on IBM PCs and compatibles. BLCC can compute the LCC for project alternatives and compare those LCCs to determine the most economic project alternative. It can compute the net savings, SIR, and payback period for any alternative relative to a base-case design. It can also generate an annual cash-flow report for each alternative and print out detailed or summary LCC analysis. [For a brochure with information on the BLCC program, contact the Office of Applied Economics at NIST, (301) 975-6132.]